Chapter 6

Mass And Energy Analysis Of Control Volumes

Objectives

- Develop the conservation of mass principle.
- Apply the conservation of mass principle to various systems including steady- and unsteady-flow control volumes.
- Apply the first law of thermodynamics as the statement of the conservation of energy principle to control volumes.

Objectives

- Identify the energy carried by a fluid stream crossing a control surface as the sum:
- Of internal energy, flow work, kinetic energy, and potential energy of the fluid
- And to relate the combination of the internal energy and the flow work to the property enthalpy.

Objectives

- Solve energy balance problems for common steady-flow devices such as nozzles, compressors, turbines, throttling valves, mixers, heaters, and heat exchangers.
- Apply the energy balance to general unsteady-flow processes with particular emphasis on the uniform-flow process as the model.

6-1 CONSERVATION OF MASS

Conservation of mass: Mass, like energy, is a conserved property, and it cannot be created or destroyed during a process.

Closed systems: The mass of the system remain constant during a process.

Control volumes: Mass can cross the boundaries, and so we must keep track of the amount of mass entering and leaving the control volume.

Mass *m* and energy *E* can be converted to each other according to

$$E = mc^2$$

where *c* is the speed of light in a vacuum, which is $c = 2.9979 \times 10^8$ m/s.

The mass change due to energy change is negligible.

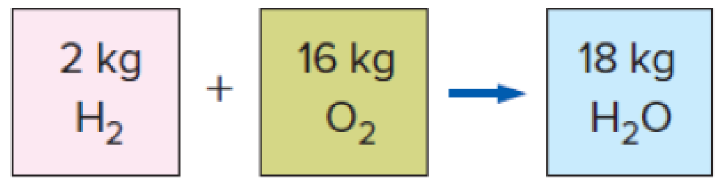


FIGURE 6-1

Mass is conserved even during chemical reaction.

Conservation of Mass Principle

$$\begin{pmatrix}\text{Total mass entering} \\ \text{the CV during } \Delta t\end{pmatrix} - \begin{pmatrix}\text{Total mass leaving} \\ \text{the CV during } \Delta t\end{pmatrix} = \begin{pmatrix}\text{Net change of mass} \\ \text{within the CV during } \Delta t\end{pmatrix}$$

The conservation of mass principle for a control volume: The net mass transfer to or from a control volume during a time interval Δt is equal to the net change (increase or decrease) in the total mass within the control volume during Δt.

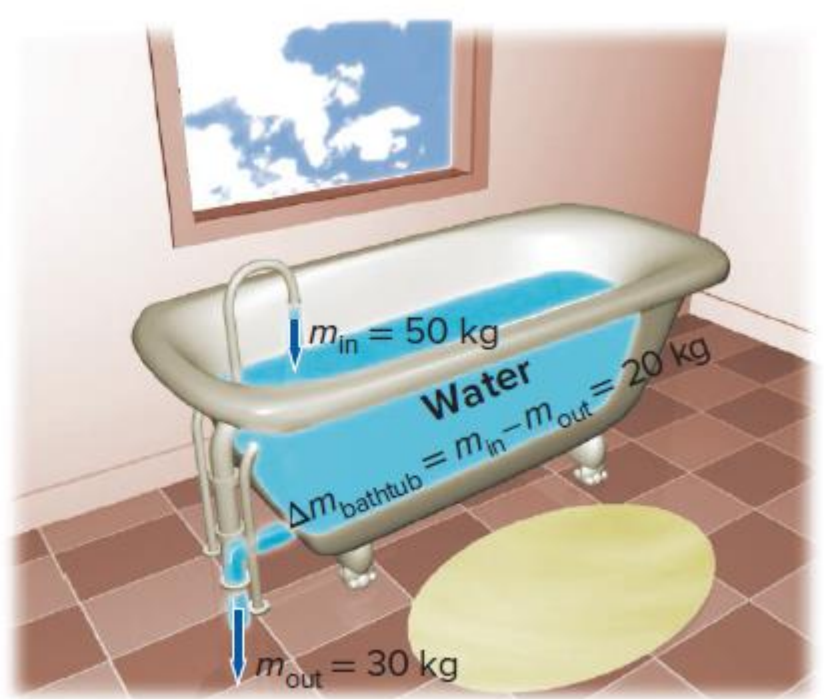


FIGURE 6-5

Conservation of mass principle for an ordinary bathtub.

$$m_{\text{in}} - m_{\text{out}} = \Delta m_{\text{CV}} \qquad \text{(kg)}$$

$$\Delta m_{\text{cv}} = m_{\text{final}} - m_{\text{initial}}$$

$$\dot{m}_{\text{in}} - \dot{m}_{\text{out}} = dm_{\text{CV}/dt} \qquad \text{(kg/s)}$$

These eequations are often referred to as the mass balance and are applicable to any control volume undergoing any kind of process.

EXAMPLE 6–1 Water Flow through a Garden Hose Nozzle

A garden hose attached with a nozzle is used to fill a 10-gal bucket. The inner diameter of the hose is 2 cm, and it reduces to 0.8 cm at the nozzle exit (Fig. 6–10). If it takes 50 s to fill the bucket with water, determine (*a*) the volume and mass flow rates of water through the hose, and (*b*) the average velocity of water at the nozzle exit.

FIGURE 6–10
Schematic for Example 6–1.

SOLUTION

A garden hose is used to fill a water bucket. The volume and mass flow rates of water and the exit velocity are to be determined.

Assumptions

1 Water is a nearly incompressible substance. **2** Flow through the hose is steady. **3** There is no waste of water by splashing.

Properties

We take the density of water to be 1000 kg/m^3 = 1 kg/L.

Analysis

(*a*) Noting that 10 gal of water is discharged in 50 s, the volume and mass flow rates of water are

$$\dot{V} = \frac{V}{\Delta t} = \frac{10 \text{ gal}}{50 \text{ s}}\left(\frac{3.7854 \text{ L}}{1 \text{ gal}}\right) = \mathbf{0.757 \text{ L/s}}$$

$$\dot{m} = \rho \dot{V} = (1 \text{ kg/L})(0.757 \text{ L/s}) = \mathbf{0.757 \text{ kg/s}}$$

(*b*) The cross-sectional area of the nozzle exit is

$$A_e = \pi r_e^2 = \pi(0.4 \text{ cm})^2 = 0.5027 \text{ cm}^2 = 0.5027 \times 10^{-4} \text{ m}^2$$

The volume flow rate through the hose and the nozzle is constant. Then the average velocity of water at the nozzle exit becomes

$$V_e = \frac{\dot{V}}{A_e} = \frac{0.757 \text{ L/s}}{0.5027 \times 10^{-4} \text{ m}^2}\left(\frac{1 \text{m}^3}{1000 \text{ L}}\right) = \mathbf{15.1 \text{ m/s}}$$

Discussion

It can be shown that the average velocity in the hose is 2.4 m/s. Therefore, the nozzle increases the water velocity by over six times.

Mass Balance for Steady-Flow Processes

During a steady-flow process, the total amount of mass contained within a control volume does not change with time (m_{CV} = constant).

Then the conservation of mass principle requires that the total amount of mass entering a control volume equal the total amount of mass leaving it.

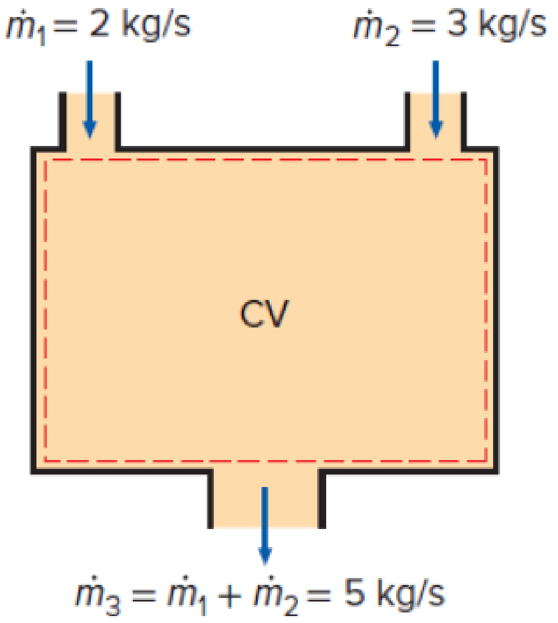


FIGURE 6-8

Conservation of mass principle for a two-inlet-one-outlet steady-flow system.

For steady-flow processes, we are interested in the amount of mass flowing per unit time, that is, *the mass flow rate.*

$$\sum_{in} \dot{m} = \sum_{out} \dot{m} \qquad \text{(kg/s)}$$

Multiple inlets and exits

$$\dot{m}_1 = \dot{m}_2 \longrightarrow \rho_1 V_1 A_1 = \rho_2 V_2 A_2$$

Single stream

Many engineering devices such as nozzles, diffusers, turbines, compressors, and pumps involve a single stream (only one inlet and one outlet).

Special Case: Incompressible Flow

The conservation of mass relations can be simplified even further when the fluid is incompressible, which is usually the case for liquids.

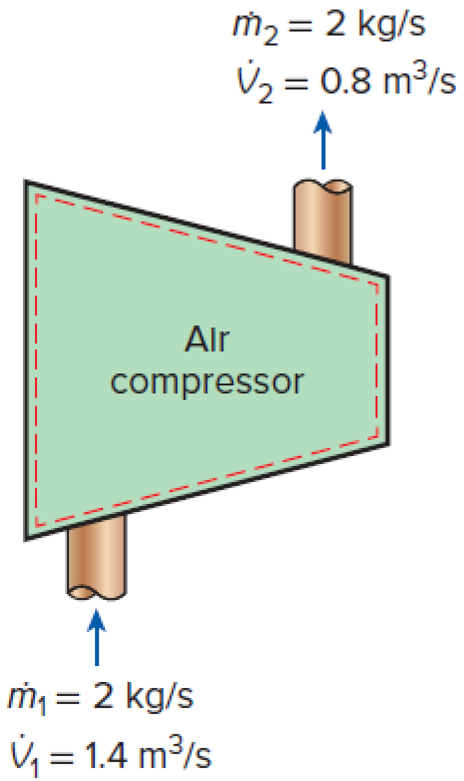


FIGURE 6-9

During a steady-flow process, volume flow rates are not necessarily conserved although mass flow rates are.

$$\sum_{\text{in}} \dot{V} = \sum_{\text{out}} \dot{V} \qquad (\text{m}^3/\text{s})$$

Steady, incompressible

$$\dot{V}_1 = \dot{V}_2 \longrightarrow V_1 A_1 = V_2 A_2$$

Steady, incompressible flow(single stream)

There is no such thing as a "conservation of volume" principle.

For steady flow of liquids, the volume flow rates, as well as the mass flow rates, remain constant since liquids are essentially incompressible substances.

Total Energy of a Flowing Fluid

$$e = u + \text{ke} + \text{pe} = u + \frac{V^2}{2} + gz \qquad \text{(kJ/kg)}$$

Energy of a **flowing fluid**

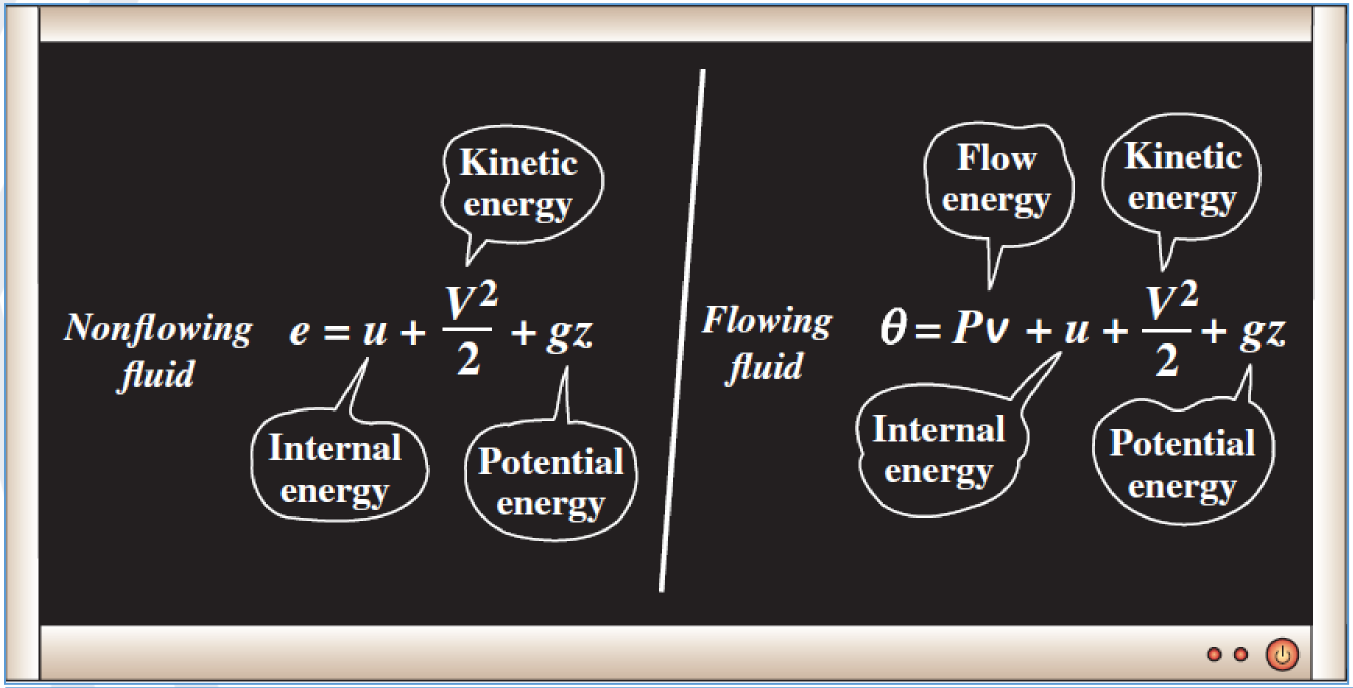
(denoted by θ)

$$\theta = Pv + e = Pv + (u + \text{ke} + \text{pe})$$

$$h = u + Pv$$

$$\theta = h + \text{ke} + \text{pe} = h + \frac{V^2}{2} + gz \qquad \text{(kJ/kg)}$$

The flow energy is automatically taken care of by enthalpy. In fact, this is the main reason for defining the property enthalpy.



The total energy consists of three parts for a non-flowing fluid and four parts for a flowing fluid.

A flowing liquid is that which has relative motion between its layers and pipe body.
It is of two types-

1.**Streamlined==>** Type of flow in which the particle follow the path of its preceding particle's path. Its *Reynolds number* is from 1000 to 3000.
2.**Turbulent==>** Type of flow in which particles of fluid don't have a specific path its *Reynolds number* is below 1000 or more than 3000.

A non flowing liquid is that fluid which doesn't have a relative motion with respect to inner body of vessel or pipe in which it is in touch with.

6-3 ENERGY ANALYSIS OF STEADY-FLOW SYSTEMS

Steady-flow process: ***A process during which a fluid flows through a control volume steadily*.**

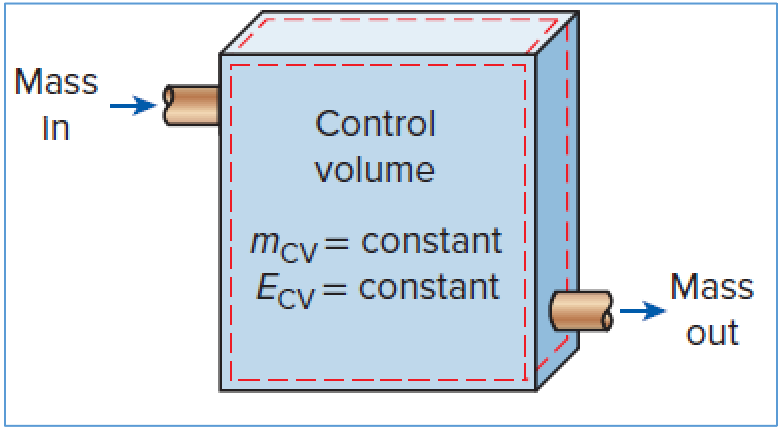


FIGURE 6-19

Under steady-flow conditions, the mass and energy contents of a control volume remains constant.

FIGURE 6-18

Many engineering systems such as power plants operate under steady conditions.

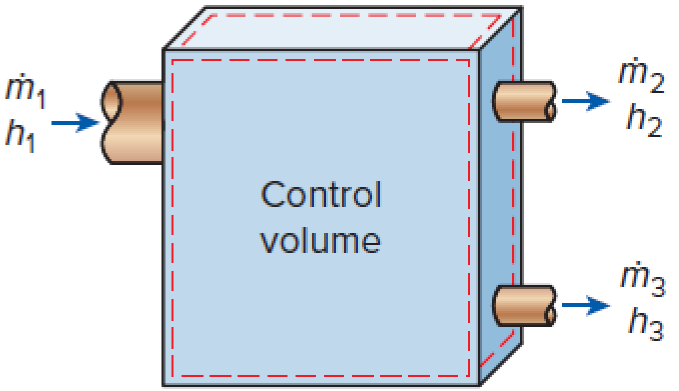


FIGURE 6-20

Under steady-flow conditions, the fluid properties at an inlets or exits remains constant(do not change with time).

Ex-6-3

EXAMPLE 6–3 Energy Transport by Mass

Steam is leaving a 4-L pressure cooker whose operating pressure is 150 kPa (Fig. 6–17). It is observed that the amount of liquid in the cooker has decreased by 0.6 L in 40 min after the steady operating conditions are established, and the cross-sectional area of the exit opening is 8 mm^2. Determine (*a*) the mass flow rate of the steam and the exit velocity, (*b*) the total and flow energies of the steam per unit mass, and (*c*) the rate at which energy leaves the cooker by steam.

FIGURE 6–17
Schematic for Example 6–3.

SOLUTION

Steam leaves a pressure cooker at a specified pressure. The velocity, flow rate, the total and flow energies, and the rate of energy transfer by mass are to be determined.

Assumptions

1 The flow is steady, and the initial start-up period is disregarded. **2** The kinetic and potential energies are negligible, and thus they are not considered. **3** Saturation conditions exist within the cooker at all times so that steam leaves the cooker as a saturated vapor at the cooker pressure.

Properties

The properties of saturated liquid water and water vapor at 150 kPa are $v_f = 0.001053$ m^3/kg, $v_g = 1.1594$ m^3/kg, $u_g = 2519.2$ kJ/kg, and $h_g = 2693.1$ kJ/kg (Table A–5).

Analysis

(*a*) Saturation conditions exist in a pressure cooker at all times after the steady operating conditions are established. Therefore, the liquid has the properties of saturated liquid and the exiting steam has the properties of saturated vapor at the operating pressure. The amount of liquid that has evaporated, the mass flow rate of the exiting steam, and the exit velocity are

$$m = \frac{\Delta V_{\text{liquid}}}{v_f} = \frac{0.6\text{ L}}{0.001053\text{ m}^3/\text{kg}}\left(\frac{1\text{ m}^3}{1000\text{ L}}\right) = 0.570\text{ kg}$$

$$\dot{m} = \frac{m}{\Delta t} = \frac{0.570\text{ kg}}{40\text{ min}} = 0.0142\text{ kg/min} = \mathbf{2.37 \times 10^{-4}\ kg/s}$$

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Ex-6-3

(*b*) Noting that $h = u + Pv$ and that the kinetic and potential energies are disregarded, the flow and total energies of the exiting steam are

$$e_{\text{flow}} = Pv = h - u = 2693.1 - 2519.2 = \mathbf{173.9\ kJ/kg}$$

$$\theta = h + \text{ke} + \text{pe} \cong h = \mathbf{2693.1\ kJ/kg}$$

Note that the kinetic energy in this case is $\text{ke} = V^2/2 = (34.3\ \text{m/s})^2/2 = 588\ \text{m}^2/\text{s}^2 = 0.588$ kJ/kg, which is small compared to enthalpy.

(*c*) The rate at which energy is leaving the cooker by mass is simply the product of the mass flow rate and the total energy of the exiting steam per unit mass,

$$\dot{E}_{\text{mass}} = \dot{m}\theta = (2.37 \times 10^{-4}\ \text{kg/s})(2693.1\ \text{kJ/kg}) = 0.638\ \text{kJ/s} = \mathbf{0.638\ kW}$$

Discussion

The numerical value of the energy leaving the cooker with steam alone does not mean much since this value depends on the reference point selected for enthalpy (it could even be negative). The significant quantity is the difference between the enthalpies of the exiting vapor and the liquid inside (which is h_{fg}) since it relates directly to the amount of energy supplied to the cooker.

Mass and Energy balances for a steady-flow process

$$\sum_{in} \dot{m} = \sum_{out} \dot{m} \qquad \text{(kg/s)}$$

$$\dot{m}_1 = \dot{m}_2$$

$$\rho_1 V_1 A_1 = \rho_2 V_2 A_2$$

Mass balance

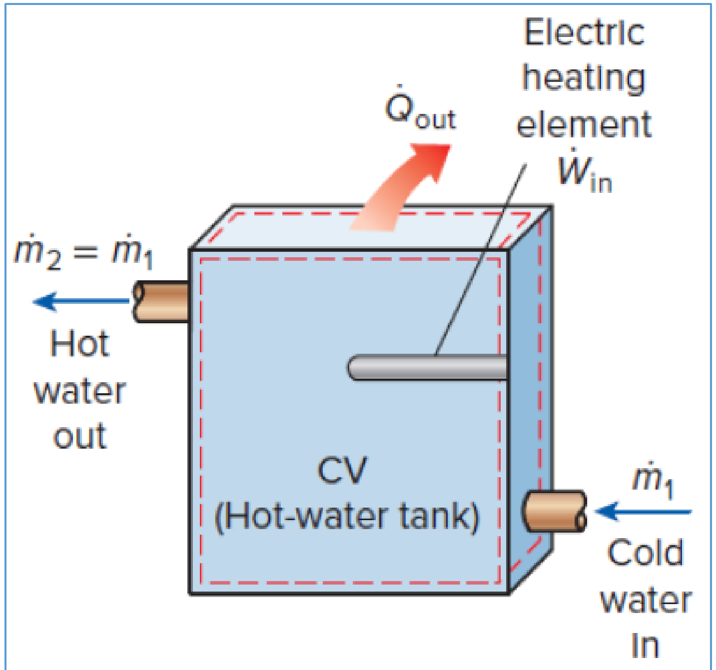


FIGURE 6-21

A water heater in steady operation.

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer in} \\ \text{by heat,work,and mass}}} = \underbrace{dE_{system}/dt^{\nearrow 0 \text{(steady)}}}_{\substack{\text{Rate of change in internal,kinetic,} \\ \text{potential,etc,.energies}}} = 0$$

$$\underbrace{\dot{E}_{in}}_{\substack{\text{Rate of net energy transfer in} \\ \text{by heat,work,and mass}}} = \underbrace{\dot{E}_{out}}_{\substack{\text{Rate of net energy transfer in} \\ \text{by heat,work,and mass}}} \qquad \text{(kW)}$$

Energy balance

$$\dot{Q}_{in} + \dot{W}_{in} + \sum_{in} \dot{m}\theta = \dot{Q}_{out} + \dot{W}_{out} + \sum_{out} \dot{m}\theta$$

$$\dot{Q}_{in} + \dot{W}_{in} + \underbrace{\textstyle\sum_{in} \dot{m}\left(h + \frac{V^2}{2} + gz\right)}_{\text{for each inlet}} = \dot{Q}_{out} + \dot{W}_{out} + \underbrace{\textstyle\sum_{out} \dot{m}\left(h + \frac{V^2}{2} + gz\right)}_{\text{for each exit}}$$

Energy balance relations with sign conventions (i.e., heat input and work output are positive)

$$\dot{Q} - \dot{W} = \sum_{\text{out}} \dot{m} \underbrace{\left(h + \frac{V^2}{2} + gz\right)}_{\text{for each exit}} - \sum_{\text{in}} \dot{m} \underbrace{\left(h + \frac{V^2}{2} + gz\right)}_{\text{for each inlet}}$$

$$h = u + Pv$$

Conversion Factor

$$\frac{\mathrm{J}}{\mathrm{kg}} \equiv \frac{\mathrm{N \cdot m}}{\mathrm{kg}} \equiv \left(\mathrm{kg}\frac{\mathrm{m}}{\mathrm{s^2}}\right)\frac{\mathrm{m}}{\mathrm{kg}} \equiv \frac{\mathrm{m^2}}{\mathrm{s^2}}$$

$$\left(\text{Also, } \frac{\mathrm{Btu}}{\mathrm{lbm}} \equiv 25{,}037\ \frac{\mathrm{ft^2}}{\mathrm{s^2}}\right)$$

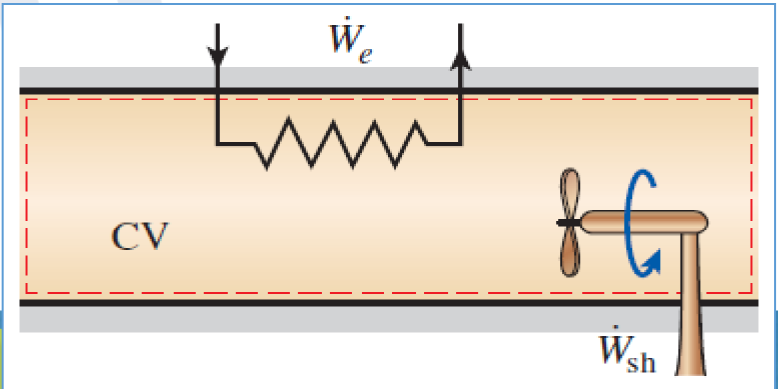
$$\dot{Q} - \dot{W} = \dot{m}\left[h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)\right]$$

$$q - w = h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)$$

$$q - w = h_2 - h_1 \qquad q = \dot{Q}/\dot{m} \qquad w = \dot{W}/\dot{m}$$

when kinetic and potential energy changes are negligible

The units m^2/s^2 and J/kg are equivalent.



Under steady operation, shaft work and electrical work are the only forms of work a simple compressible system may involve.

Nozzles and Diffusers

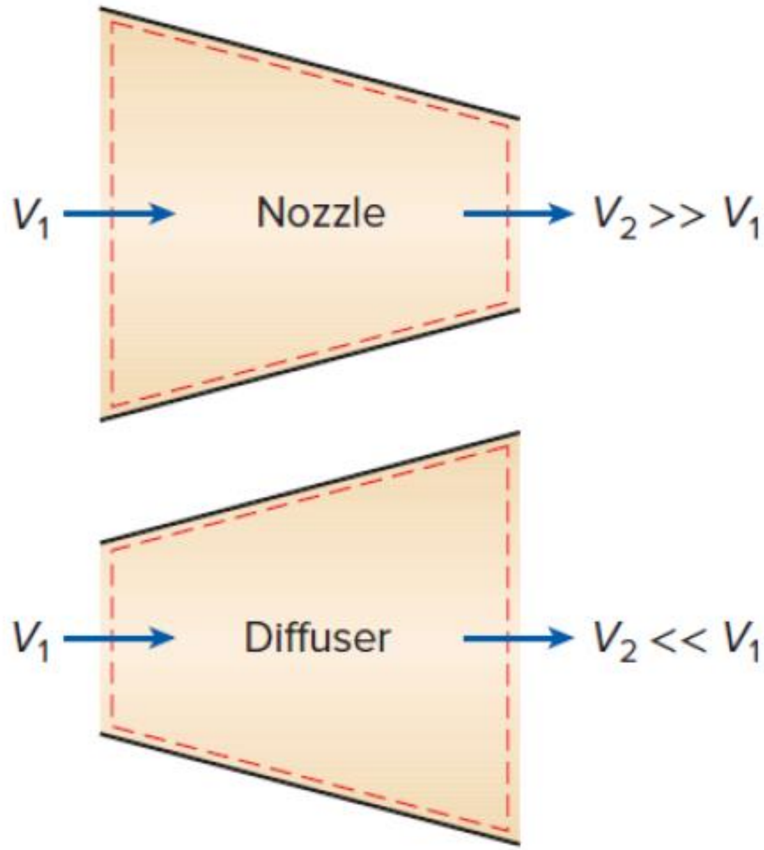


FIGURE 6-26

Nozzles and diffusers are shaped so that they cause large changes in fluid velocities and thus kinetic energies

- **Nozzles and diffusers are commonly utilized in jet engines, rockets, spacecraft, and even garden hoses.**
- **A nozzle is a device that *increases the velocity of a fluid* at the expense of pressure.**
- **A diffuser is a device that *increases the pressure of a fluid* by slowing it down.**
- **The cross-sectional area of a nozzle decreases in the flow direction for subsonic flows and increases for supersonic flows. The reverse is true for diffusers.**

Energy balance for a nozzle or diffuser:

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{m}\left(h_1 + \frac{V_1^2}{2}\right) = \dot{m}\left(h_2 + \frac{V_2^2}{2}\right)$$

$$\left(\text{since}\,\dot{Q} \cong 0, \dot{W} = 0, \text{and}\ \Delta\text{pe} \cong 0\right)$$

Deceleration of Air in a Diffuser

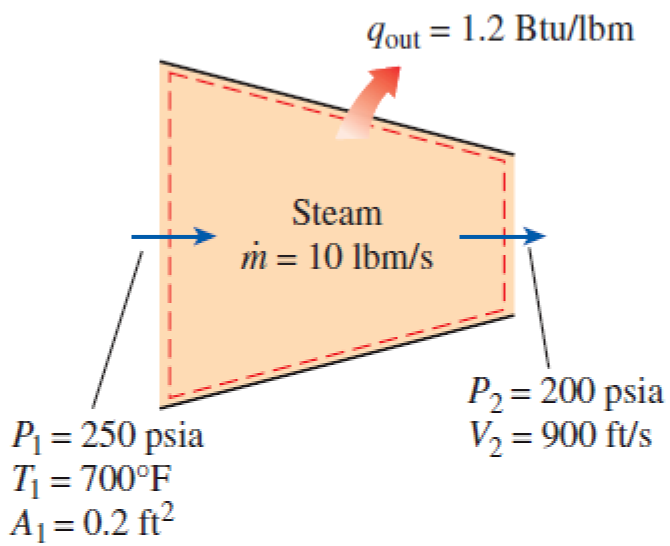
$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat ,work,and mass}}} = \underbrace{dE_{\text{system}}/dt^{\nearrow 0\text{(steady)}}}_{\substack{\text{Rate of change in internal,kinetic,}\\ \text{potential,etc,.energies}}} = 0$$

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{m}\left(h_1 + \frac{V_1^2}{2}\right) = \dot{m}\left(h_2 + \frac{V_2^2}{2}\right) \qquad \left(\text{since } \dot{Q} \cong 0, \dot{W} = 0, \text{and } \Delta\text{pe} \cong 0\right)$$

$$h_2 = h_1 - \frac{V_2^2 - V_1^2}{2}$$

Acceleration of Steam in a Nozzle



$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat ,work,and mass}}} = \underbrace{dE_{\text{system}}/dt^{\nearrow 0(\text{steady})}}_{\substack{\text{Rate of change in internal,kinetic,} \\ \text{potential,etc,.energies}}} = 0$$

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{m}\left(h_1 + \frac{V_1^2}{2}\right) = \dot{Q}_{\text{out}} + \dot{m}\left(h_2 + \frac{V_2^2}{2}\right) \quad (\text{since } \dot{W} = 0, \text{and } \Delta\text{pe} \cong 0)$$

$$h_2 = h_1 - q_{\text{out}} - \frac{V_2^2 - V_1^2}{2}$$

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Ex-6-4

EXAMPLE 6–4 Deceleration of Air in a Diffuser

Air at 10°C and 80 kPa enters the diffuser of a jet engine steadily with a velocity of 200 m/s. The inlet area of the diffuser is 0.4 m^2. The air leaves the diffuser with a velocity that is very small compared with the inlet velocity. Determine (*a*) the mass flow rate of the air and (*b*) the temperature of the air leaving the diffuser.

SOLUTION

Air enters the diffuser of a jet engine steadily at a specified velocity. The mass flow rate of air and the temperature at the diffuser exit are to be determined.

Assumptions

1 This is a steady-flow process since there is no change with time at any point and thus $\Delta m_{CV} = 0$ and $\Delta E_{CV} = 0$. **2** Air is an ideal gas since it is at a high temperature and low pressure relative to its critical-point values. **3** The potential energy change is zero, $\Delta \text{pe} = 0$. **4** Heat transfer is negligible. **5** Kinetic energy at the diffuser exit is negligible. **6** There are no work interactions.

Analysis

We take the *diffuser* as the system (Fig. 6–27). This is a *control volume* since mass crosses the system boundary during the process. We observe that there is only one inlet and one exit and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$.

Ex-6-4

FIGURE 6–27
The diffuser of a jet engine discussed in **Example 6–4**.

(*a*) To determine the mass flow rate, we need to find the specific volume of the air first. This is determined from the ideal-gas relation at the inlet conditions:

$$v_1 = \frac{RT_1}{P_1} = \frac{(0.287 \text{ kPa·m}^3/\text{kg·K})(283 \text{ K})}{80 \text{ kPa}} = 1.015 \text{ m}^3/\text{kg}$$

Then,

$$\dot{m} = \frac{1}{v_1} V_1 A_1 = \frac{1}{1.015 \text{ m}^3/\text{kg}} (200 \text{ m/s})(0.4 \text{ m}^2) = \mathbf{78.8 \text{ kg/s}}$$

Since the flow is steady, the mass flow rate through the entire diffuser remains constant at this value.

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(*b*) Under stated assumptions and observations, the energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc., energies}}} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{m}\left(h_1 + \frac{V_1^2}{2}\right) = \dot{m}\left(h_2 + \frac{V_2^2}{2}\right) \quad (\text{since } \dot{Q} \cong 0,\ \dot{W} = 0, \text{ and } \Delta\text{pe} \cong 0)$$

$$h_2 = h_1 - \frac{V_2^2 - V_1^2}{2}$$

The exit velocity of a diffuser is usually small compared with the inlet velocity ($V_2 << V_1$); thus, the kinetic energy at the exit can be neglected. The enthalpy of air at the diffuser inlet is determined from the air table (**Table A–21**) to be

$$h_1 = h_{@\,283\text{ K}} = 283.14 \text{ kJ/kg}$$

Substituting, we get

$$h_2 = 283.14 \text{ kJ/kg} - \frac{0 - (200 \text{ m/s})^2}{2}\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right)$$
$$= 303.14 \text{ kJ/kg}$$

Ex-6-4

From **Table A–21**, the temperature corresponding to this enthalpy value is

$$T_2 = \mathbf{303\ K}$$

Discussion

This result shows that the temperature of the air increases by about 20°C as it is slowed down in the diffuser. The temperature rise of the air is mainly due to the conversion of kinetic energy to internal energy.

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Ex-6-5

EXAMPLE 6–5 Acceleration of Steam in a Nozzle

Steam at 250 psia and 700°F steadily enters a nozzle whose inlet area is 0.2 ft^2. The mass flow rate of steam through the nozzle is 10 lbmys. Steam leaves the nozzle at 200 psia with a velocity of 900 ft/s. Heat losses from the nozzle per unit mass of the steam are estimated to be 1.2 Btu/lbm. Determine (*a*) the inlet velocity and (*b*) the exit temperature of the steam.

SOLUTION

Steam enters a nozzle steadily at a specified flow rate and velocity. The inlet velocity of steam and the exit temperature are to be determined.

Assumptions

1 This is a steady-flow process since there is no change with time at any point and thus $\Delta m_{CV} = 0$ and $\Delta E_{CV} = 0$. **2** There are no work interactions. **3** The potential energy change is zero, Δ pe = 0.

Analysis

We take the *nozzle* as the system (**Fig. 6–28**). This is a *control volume* since mass crosses the system boundary during the process. We observe that there is only one inlet and one exit and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$.

Ex-6-5

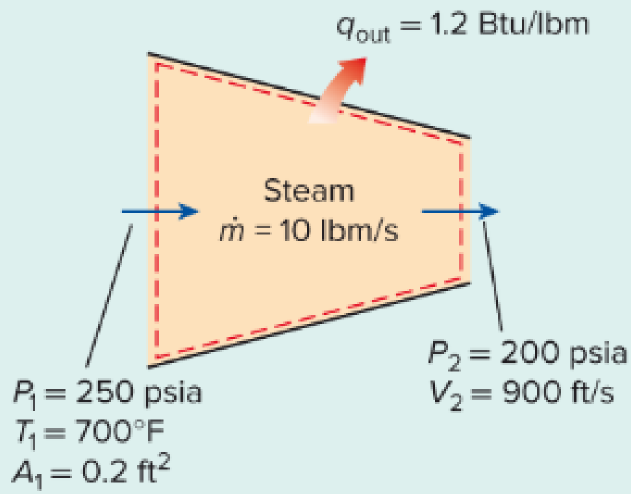

FIGURE 6–28
Schematic for **Example 6–5**.

(*a*) The specific volume and enthalpy of steam at the nozzle inlet are

$$\left.\begin{aligned} P_1 &= 250 \text{ psia} \\ T_1 &= 700°\text{F} \end{aligned}\right\} \begin{aligned} v_1 &= 2.6883 \text{ ft}^3/\text{lbm} \\ h_1 &= 1371.4 \text{ Btu/lbm} \end{aligned} \quad \text{(Table A–6E)}$$

Then,

$$\dot{m} = \frac{1}{v_1} V_1 A_1$$

$$10 \text{ lbm/s} = \frac{1}{2.6883 \text{ ft}^3/\text{lbm}} (V_1)(0.2 \text{ ft}^2)$$

$$V_1 = \mathbf{134.4 \text{ ft/s}}$$

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Ex-6-5

(*b*) Under stated assumptions and observations, the energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc., energies}}} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{m}\left(h_1 + \frac{V_1^2}{2}\right) = \dot{Q}_{out} + \dot{m}\left(h_2 + \frac{V_2^2}{2}\right) \quad (\text{since } \dot{W} = 0, \text{ and } \Delta\text{pe} \cong 0)$$

Dividing by the mass flow rate $\dot{m}$ and substituting, h_2 is determined to be

$$h_2 = h_1 - q_{out} - \frac{V_2^2 - V_1^2}{2}$$

$$= (1371.4 - 1.2) \text{ Btu/lbm} - \frac{(900 \text{ ft/s})^2 - (134.4 \text{ ft/s})^2}{2}\left(\frac{1 \text{ Btu/lbm}}{25{,}037 \text{ ft}^2/\text{s}^2}\right)$$

$$= 1354.4 \text{ Btu/lbm}$$

Then,

$$\left.\begin{array}{l} P_2 = 200 \text{ psia} \\ h_2 = 1354.4 \text{ Btu/lbm} \end{array}\right\} T_2 = \mathbf{662.0°F} \qquad \text{(Table A–6E)}$$

Discussion

Note that the temperature of steam drops by 38.0°F as it flows through the nozzle. This drop in temperature is mainly due to the conversion of internal energy to kinetic energy. (The heat loss is too small to cause any significant effect in this case.)

Turbines and Compressors

FIGURE 6-29

Turbine blades attached to the turbine shaft.

Turbine drives the electric generator In steam, gas, or hydroelectric power plants.

As the fluid passes through the turbine, work is done against the blades, which are attached to the shaft. As a result, the shaft rotates, and the turbine produces work.

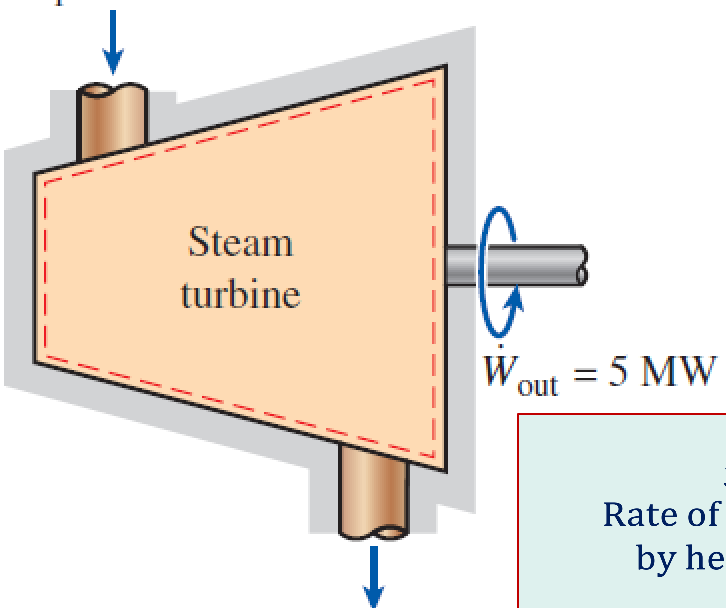
Compressors, as well as **pumps** and **fans**, are devices used to increase the pressure of a fluid. Work is supplied to these devices from an external source through a rotating shaft.

A *compressor* is capable of compressing the gas to very high pressures.

A *fan* increases the pressure of a gas slightly and is mainly used to mobilize a gas.

Pumps work very much like compressors except that they handle liquids instead of gases.

Power Generation by a Steam Turbine



$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\text{Rate of net energy transfer by heat, work, and mass}} = \underbrace{dE_{system}/dt^{\nearrow 0\text{(steady)}}}_{\text{Rate of change in internal, kinetic, potential, etc., energies}} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{m}\left(h_1 + \frac{V_1^2}{2} + gz_1\right) = \dot{W}_{out} + \dot{m}\left(h_2 + \frac{V_2^2}{2} + gz_2\right) (\text{since } \dot{Q} = 0)$$

$$w_{out} = -\left[(h_2 - h_1) + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)\right] = -(\Delta h + \Delta \mathrm{ke} + \Delta \mathrm{pe})$$

Ex-6-6

EXAMPLE 6–6 Compressing Air by a Compressor

Air at 100 kPa and 280 K is compressed steadily to 600 kPa and 400 K. The mass flow rate of the air is 0.02 kg/s, and a heat loss of 16 kJ/kg occurs during the process. Assuming the changes in kinetic and potential energies are negligible, determine the necessary power input to the compressor.

SOLUTION

Air is compressed steadily by a compressor to a specified temperature and pressure. The power input to the compressor is to be determined.

Assumptions

1 This is a steady-flow process since there is no change with time at any point and thus $\Delta m_{CV} = 0$ and $\Delta E_{CV} = 0$. **2** Air is an ideal gas since it is at a high temperature and low pressure relative to its critical-point values. **3** The kinetic and potential energy changes are zero, $\Delta ke = \Delta pe = 0$.

Analysis

We take the *compressor* as the system (**Fig. 6–30**). This is a *control volume* since mass crosses the system boundary during the process. We observe that there is only one inlet and one exit and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. Also, heat is lost from the system and work is supplied to the system.

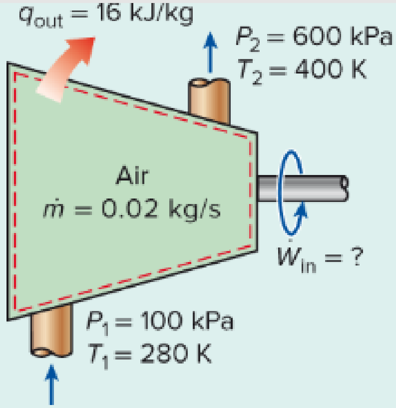


FIGURE 6–30
Schematic for **Example 6–6**.

Ex-6-6

Under stated assumptions and observations, the energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc., energies}}} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{W}_{in} + \dot{m}h_1 = \dot{Q}_{out} + \dot{m}h_2 \qquad (\text{since } \Delta\text{ke} = \Delta\text{pe} \cong 0)$$

$$\dot{W}_{in} = \dot{m}q_{out} + \dot{m}(h_2 - h_1)$$

The enthalpy of an ideal gas depends on temperature only, and the enthalpies of the air at the specified temperatures are determined from the air table (**Table A–21**) to be

$$h_1 = h_{@\,280\text{ K}} = 280.13 \text{ kJ/kg}$$

$$h_2 = h_{@\,400\text{ K}} = 400.98 \text{ kJ/kg}$$

Substituting, the power input to the compressor is determined to be

$$\dot{W}_{in} = (0.02 \text{ kg/s})(16 \text{ kJ/kg}) + (0.02 \text{ kg/s})(400.98 - 280.13) \text{ kJ/kg}$$
$$= \mathbf{2.74 \text{ kW}}$$

Discussion

Note that the mechanical energy input to the compressor manifests itself as a rise in enthalpy of air and heat loss from the compressor.

Ex-6-7

EXAMPLE 6–7 **Power Generation by a Steam Turbine**

The power output of an adiabatic steam turbine is 5 MW, and the inlet and the exit conditions of the steam are as indicated in Fig. 6–31.

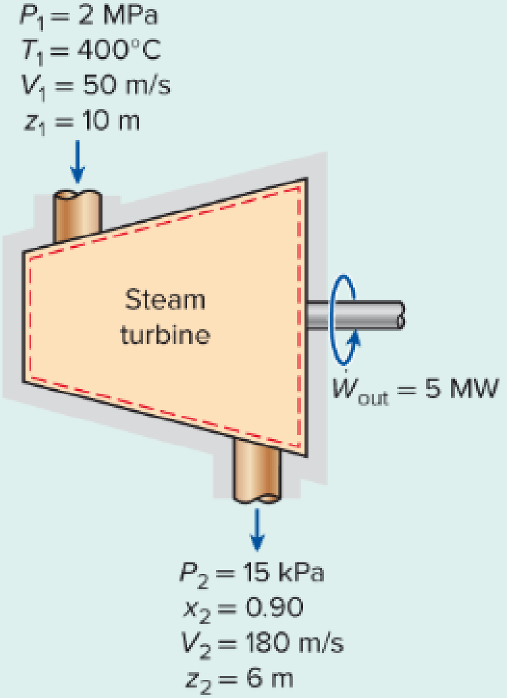


FIGURE 6–31
Schematic for **Example 6–7**.

(a) Compare the magnitudes of Δh, Δke, and Δpe.

(b) Determine the work done per unit mass of the steam flowing through the turbine.

(c) Calculate the mass flow rate of the steam.

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Ex-6-7

SOLUTION

The inlet and exit conditions of a steam turbine and its power output are given. The changes in kinetic energy, potential energy, and enthalpy of steam, as well as the work done per unit mass and the mass flow rate of steam are to be determined.

Assumptions

1 This is a steady-flow process since there is no change with time at any point and thus $\Delta m_{CV} = 0$ and $\Delta E_{CV} = 0$. **2** The system is adiabatic and thus there is no heat transfer.

Analysis

We take the *turbine* as the system. This is a *control volume* since mass crosses the system boundary during the process. We observe that there is only one inlet and one exit and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. Also, work is done by the system. The inlet and exit velocities and elevations are given, and thus the kinetic and potential energies are to be considered.

(*a*) At the inlet, steam is in a superheated vapor state, and its enthalpy is

$$\left.\begin{array}{l} P_1 = 2 \text{ MPa} \\ T_1 = 400°\text{C} \end{array}\right\} \quad h_1 = 3248.4 \text{ kJ/kg} \qquad \text{(Table A–6)}$$

At the turbine exit, we obviously have a saturated liquid–vapor mixture at 15-kPa pressure. The enthalpy at this state is

$$h_2 = h_f + x_2 h_{fg} = [225.94 + (0.9)(2372.3)] \text{ kJ/kg} = 2361.01 \text{ kJ/kg}$$

Then

$$\Delta h = h_2 - h_1 = (2361.01 - 3248.4) \text{ kJ/kg} = \mathbf{-887.39 \text{ kJ/kg}}$$

Ex-6-7

$$\Delta ke = \frac{V_2^2 - V_1^2}{2} = \frac{(180\text{ m/s})^2 - (50\text{ m/s})^2}{2}\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = \mathbf{14.95\ kJ/kg}$$

$$\Delta pe = g(z_2 - z_1) = (9.81\text{ m/s}^2)[(6 - 10)\text{ m}]\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = \mathbf{-0.04\ kJ/kg}$$

(*b*) The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt^{\nearrow 0\text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc., energies}}} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{m}\left(h_1 + \frac{V_1^2}{2} + gz_1\right) = \dot{W}_{out} + \dot{m}\left(h_2 + \frac{V_2^2}{2} + gz_2\right) \qquad (\text{since } \dot{Q} = 0)$$

Dividing by the mass flow rate $\dot{m}$ and substituting, the work done by the turbine per unit mass of the steam is determined to be

$$w_{out} = -\left[(h_2 - h_1) + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)\right] = -(\Delta h + \Delta ke + \Delta pe)$$

$$= -[-887.39 + 14.95 - 0.04]\text{ kJ/kg} = \mathbf{872.48\ kJ/kg}$$

(*c*) The required mass flow rate for a 5-MW power output is

$$\dot{m} = \frac{\dot{W}_{out}}{w_{out}} = \frac{5000\text{ kJ/s}}{872.48\text{ kJ/kg}} = \mathbf{5.73\ kg/s}$$

Discussion

Two observations can be made from these results. First, the change in potential energy is insignificant in comparison to the changes in enthalpy and kinetic energy. This is typical for most engineering devices. Second, as a result of low pressure and thus high specific volume, the steam velocity at the turbine exit can be very high. Yet the change in kinetic energy is a small fraction of the change in enthalpy (less than 2 percent in our case) and is therefore often neglected.

EXAMPLE 6–9 Mixing of Hot and Cold Waters in a Shower

Consider an ordinary shower where hot water at 140°F is mixed with cold water at 50°F. If it is desired that a steady stream of warm water at 110°F be supplied, determine the ratio of the mass flow rates of the hot to cold water. Assume the heat losses from the mixing chamber to be negligible and the mixing to take place at a pressure of 20 psia.

SOLUTION

In a shower, cold water is mixed with hot water at a specified temperature. For a specified mixture temperature, the ratio of the mass flow rates of the hot to cold water is to be determined.

Assumptions

1 This is a steady-flow process since there is no change with time at any point and thus $\Delta m_{CV} = 0$ and $\Delta E_{CV} = 0$. **2** The kinetic and potential energies are negligible, ke $\cong$ pe $\cong$ 0. **3** Heat losses from the system are negligible and thus $\dot{Q} \cong 0$. **4** There is no work interaction involved.

Analysis

We take the *mixing chamber* as the system (**Fig. 6–36**). This is a *control volume* since mass crosses the system boundary during the process. We observe that there are two inlets and one exit.

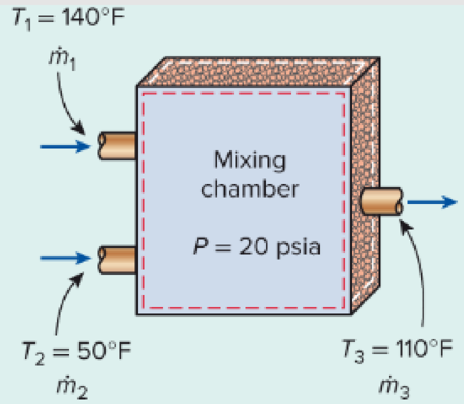

FIGURE 6–36
Schematic for **Example 6–9**.

Under the stated assumptions and observations, the mass and energy balances for this steady-flow system can be expressed in the rate form as follows:

$$\textit{Mass balance:} \quad \dot{m}_{\text{in}} - \dot{m}_{\text{out}} = \overbrace{dm_{\text{system}}/dt}^{0\text{ (steady)}} = 0$$

$$\dot{m}_{\text{in}} = \dot{m}_{\text{out}} \rightarrow \dot{m}_1 + \dot{m}_2 = \dot{m}_3$$

$$\textit{Energy balance:} \quad \underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\overbrace{dE_{\text{system}}/dt}^{0\text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc., energies}}} = 0$$

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3 \qquad (\text{since } \dot{Q} \cong 0,\ \dot{W} = 0,\ \text{ke} \cong \text{pe} \cong 0)$$

Combining the mass and energy balances,

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 = (\dot{m}_1 + \dot{m}_2) h_3$$

Dividing this equation by $\dot{m}_2$ yields

$$yh_1 + h_2 = (y + 1)h_3$$

where $y = \dot{m}_1/\dot{m}_2$ is the desired mass flow rate ratio.

The saturation temperature of water at 20 psia is 227.92°F. Since the temperatures of all three streams are below this value ($T < T_{sat}$), the water in all three streams exists as a compressed liquid (**Fig. 6–37**). A compressed liquid can be approximated as a saturated liquid at the given temperature. Thus,

$$h_1 \cong h_{f\,@\,140°F} = 107.99\ \text{Btu/lbm}$$

$$h_2 \cong h_{f\,@\,50°F} = 18.07\ \text{Btu/lbm}$$

$$h_3 \cong h_{f\,@\,110°F} = 78.02\ \text{Btu/lbm}$$

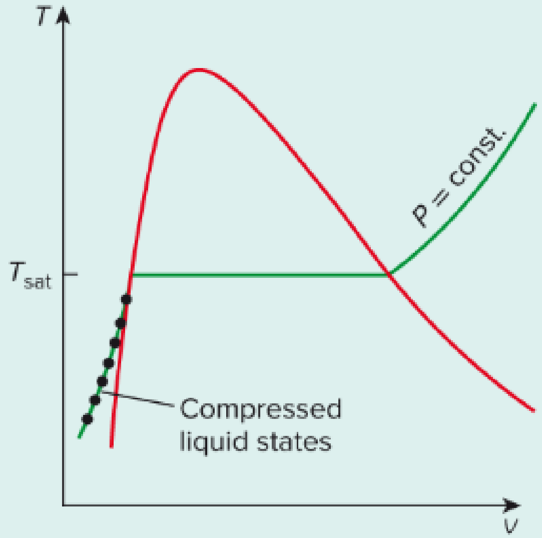

FIGURE 6–37
A substance exists as a compressed liquid at temperatures below the saturation temperatures at the given pressure.

Solving for y and substituting yields

$$y = \frac{h_3 - h_2}{h_1 - h_3} = \frac{78.02 - 18.07}{107.99 - 78.02} = \mathbf{2.0}$$

Discussion

Note that the mass flow rate of the hot water must be twice the mass flow rate of the cold water for the mixture to leave at 110°F.

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TABLE A–13

Superheated refrigerant-134a

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
	P = 0.06 MPa (T_{sat} = −36.95°C)				P = 0.10 MPa (T_{sat} = −26.37°C)				P = 0.14 MPa (T_{sat} = −18.77°C)			
Sat.	0.31108	209.13	227.80	0.9645	0.19255	215.21	234.46	0.9519	0.14020	219.56	239.19	0.9447
−20	0.33608	220.62	240.78	1.0175	0.19841	219.68	239.52	0.9721				
−10	0.35048	227.57	248.60	1.0478	0.20743	226.77	247.51	1.0031	0.14605	225.93	246.37	0.9724
0	0.36476	234.67	256.56	1.0775	0.21630	233.97	255.60	1.0333	0.15263	233.25	254.61	1.0032
10	0.37893	241.94	264.68	1.1067	0.22506	241.32	263.82	1.0628	0.15908	240.68	262.95	1.0331
20	0.39302	249.37	272.95	1.1354	0.23373	248.81	272.18	1.0919	0.16544	248.24	271.40	1.0625
30	0.40705	256.97	281.39	1.1637	0.24233	256.46	280.69	1.1204	0.17172	255.95	279.99	1.0913
40	0.42102	264.73	289.99	1.1916	0.25088	264.27	289.36	1.1485	0.17794	263.80	288.72	1.1196
50	0.43495	272.66	298.75	1.2192	0.25937	272.24	298.17	1.1762	0.18412	271.81	297.59	1.1475
60	0.44883	280.75	307.68	1.2464	0.26783	280.36	307.15	1.2036	0.19025	279.97	306.61	1.1750
70	0.46269	289.01	316.77	1.2732	0.27626	288.65	316.28	1.2306	0.19635	288.29	315.78	1.2021
80	0.47651	297.43	326.02	1.2998	0.28465	297.10	325.57	1.2573	0.20242	296.77	325.11	1.2289
90	0.49032	306.02	335.43	1.3261	0.29303	305.71	335.01	1.2836	0.20847	305.40	334.59	1.2554
100	0.50410	314.76	345.01	1.3521	0.30138	314.48	344.61	1.3097	0.21449	314.19	344.22	1.2815
	P = 0.18 MPa (T_{sat} = −12.73°C)				P = 0.20 MPa (T_{sat} = −10.09°C)				P = 0.24 MPa (T_{sat} = −5.38°C)			
Sat.	0.11049	223.01	242.90	0.9398	0.09995	224.51	244.50	0.9379	0.08398	227.17	247.32	0.9348
−10	0.11189	225.04	245.18	0.9485	0.09991	224.57	244.56	0.9381				
0	0.11722	232.49	253.59	0.9799	0.10481	232.11	253.07	0.9699	0.08617	231.30	251.98	0.9520
10	0.12240	240.02	262.05	1.0103	0.10955	239.69	261.60	1.0005	0.09026	239.00	260.66	0.9832
20	0.12748	247.66	270.60	1.0400	0.11418	[illegible]	270.20	1.0304	0.09423	246.76	269.38	1.0134
30	0.13248	255.43	279.27	1.0691	0.11874	255.16	278.91	1.0596	0.09812	254.63	278.17	1.0429
40	0.13741	263.33	288.07	1.0976	0.12322	263.09	287.74	1.0882	0.10193	262.61	287.07	1.0718
50	0.14230	271.38	297.00	1.1257	0.12766	271.16	296.70	1.1164	0.10570	270.73	296.09	1.1002
60	0.14715	279.58	306.07	1.1533	0.13206	279.38	305.79	1.1441	0.10942	278.98	305.24	1.1281
70	0.15196	287.93	315.28	1.1806	0.13641	287.75	315.03	1.1714	0.11310	287.38	314.53	1.1555
80	0.15673	296.43	324.65	1.2075	0.14074	296.27	324.41	1.1984	0.11675	295.93	323.95	1.1826
90	0.16149	305.09	334.16	1.2340	0.14504	304.93	333.94	1.2250	0.12038	304.62	333.51	1.2093
100	0.16622	313.90	343.82	1.2603	0.14933	313.75	343.62	1.2513	0.12398	313.46	343.22	1.2356
	P = 0.28 MPa (T_{sat} = −1.25°C)				P = 0.32 MPa (T_{sat} = 2.46°C)				P = 0.40 MPa (T_{sat} = 8.91°C)			
Sat.	0.07243	229.49	249.77	0.9323	0.06368	231.55	251.93	0.9303	0.051266	235.10	255.61	0.9271
0	0.07282	230.46	250.85	0.9362								
10	0.07646	238.29	259.70	0.9681	0.06609	237.56	258.70	0.9545	0.051506	235.99	256.59	0.9306
20	0.07997	246.15	268.54	0.9987	0.06925	245.51	267.67	0.9856	0.054213	244.19	265.88	0.9628
30	0.08338	254.08	277.42	1.0285	0.07231	253.52	276.66	1.0158	0.056796	252.37	275.09	0.9937
40	0.08672	262.12	286.40	1.0577	0.07530	261.62	285.72	1.0452	0.059292	260.60	284.32	1.0237
50	0.09000	270.28	295.48	1.0862	0.07823	269.83	294.87	1.0739	0.061724	268.92	293.61	1.0529
60	0.09324	278.58	304.69	1.1143	0.08111	278.17	304.12	1.1022	0.064104	277.34	302.98	1.0814
70	0.09644	287.01	314.01	1.1419	0.08395	286.64	313.50	1.1299	0.066443	285.88	312.45	1.1095
80	0.09961	295.59	323.48	1.1690	0.08675	295.24	323.00	1.1572	0.068747	294.54	322.04	1.1370
90	0.10275	304.30	333.07	1.1958	0.08953	303.99	332.64	1.1841	0.071023	303.34	331.75	1.1641
100	0.10587	313.17	342.81	1.2223	0.09229	312.87	342.41	1.2106	0.073274	312.28	341.59	1.1908
110	0.10897	322.18	352.69	1.2484	0.09503	321.91	352.31	1.2368	0.075504	321.35	351.55	1.2172
120	0.11205	331.34	362.72	1.2742	0.09775	331.08	362.36	1.2627	0.077717	330.56	361.65	1.2432
130	0.11512	340.65	372.88	1.2998	0.10045	340.41	372.55	1.2883	0.079913	339.92	371.89	1.2689
140	0.11818	350.11	383.20	1.3251	0.10314	349.88	382.89	1.3136	0.082096	349.42	382.26	1.2943

Specific Volume at 200 KPa and 20 °C

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TABLE A–13E

Superheated refrigerant-134a (*Concluded*)

T °F	*v* ft³/lbm	*u* Btu/lbm	*h* Btu/lbm	*s* Btu/lbm·R	*v* ft³/lbm	*u* Btu/lbm	*h* Btu/lbm	*s* Btu/lbm·R	*v* ft³/lbm	*u* Btu/lbm	*h* Btu/lbm	*s* Btu/lbm·R
	P = 90 psia (T_{sat} = 72.78°F)				P = 100 psia (T_{sat} = 79.12°F)				P = 120 psia (T_{sat} = 90.49°F)			
Sat.	0.53173	104.23	113.08	0.22011	0.47811	105.01	113.85	0.21981	0.39681	106.37	115.18	0.21928
80	0.54388	105.75	114.81	0.22332	0.47906	105.19	114.06	0.22018				
100	0.57729	109.91	119.53	0.23191	0.51076	109.46	118.91	0.22902	0.41013	108.49	117.59	0.22364
120	0.60874	114.05	124.19	0.24009	0.54022	113.66	123.66	0.23735	0.43692	112.85	122.55	0.23234
140	0.63885	118.20	128.84	0.24799	0.56821	117.86	128.38	0.24535	0.46190	117.16	127.42	0.24059
160	0.66796	122.39	133.51	0.25565	0.59513	122.09	133.10	0.25310	0.48563	121.47	132.25	0.24853
180	0.69629	126.63	138.22	0.26313	0.62122	126.36	137.85	0.26065	0.50844	125.80	137.09	0.25621
200	0.72399	130.92	142.98	0.27045	0.64667	130.68	142.64	0.26802	0.53054	130.18	141.96	0.26370
220	0.75119	135.28	147.79	0.27763	0.67158	135.05	147.48	0.27525	0.55206	134.60	146.86	0.27102
240	0.77796	139.70	152.66	0.28469	0.69605	139.50	152.38	0.28234	0.57312	139.08	151.80	0.27819
260	0.80437	144.19	157.59	0.29164	0.72016	144.00	157.33	0.28932	0.59379	143.62	156.80	0.28523
280	0.83048	148.75	162.58	0.29849	0.74396	148.58	162.34	0.29620	0.61413	148.22	161.86	0.29216
300	0.85633	153.39	167.65	0.30524	0.76749	153.22	167.42	0.30297	0.63420	152.89	166.97	0.29898
320	0.88195	158.09	172.78	0.31191	0.79079	157.94	172.57	0.30966	0.65402	157.62	172.15	0.30571
	P = 140 psia (T_{sat} = 100.51°F)				P = 160 psia (T_{sat} = 109.50°F)				P = 180 psia (T_{sat} = 117.69°F)			
Sat.	0.33800	107.52	116.28	0.21883	0.29339	108.51	117.20	0.21840	0.25833	109.38	117.98	0.21799
120	0.36243	111.97	121.36	0.22775	0.30578	111.01	120.07	0.22339	0.26083	109.95	118.64	0.21912
140	0.38551	116.42	126.40	0.23630	0.32774	115.63	125.33	0.23232	0.28231	114.78	124.18	0.22852
160	0.40711	120.82	131.37	0.24444	0.34790	120.14	130.44	0.24070	0.30154	119.43	129.47	0.23720
180	0.42766	125.23	136.31	0.25229	0.36686	124.63	135.49	0.24872	0.31936	124.01	134.65	0.24542
200	0.44743	129.66	141.25	0.25990	0.38494	129.13	140.52	0.25647	0.33619	128.58	139.77	0.25332
220	0.46657	134.13	146.22	0.26731	0.40234	133.65	145.56	0.26399	0.35228	133.16	144.89	0.26095
240	0.48522	138.65	151.22	0.27457	0.41921	138.21	150.62	0.27133	0.36779	137.76	150.01	0.26838
260	0.50345	143.22	156.26	0.28168	0.43564	142.82	155.72	0.27851	0.38284	142.41	155.16	0.27564
280	0.52134	147.85	161.36	0.28866	0.45171	147.48	160.86	0.28555	0.39751	147.11	160.35	0.28275
300	0.53895	152.55	166.51	0.29553	0.46748	152.21	166.05	0.29248	0.41186	151.86	165.58	0.28972
320	0.55630	157.31	171.72	0.30230	0.48299	156.99	171.29	0.29929	0.42594	156.67	170.85	0.29658
340	0.57345	162.14	176.99	0.30898	0.49828	161.84	176.59	0.30600	0.43980	161.53	176.18	0.30333
360	0.59041	167.03	182.33	0.31557	0.51338	166.75	181.95	0.31262	0.45347	166.47	181.57	0.30998
	P = 200 psia (T_{sat} = 125.22°F)				P = 300 psia (T_{sat} = 156.09°F)				P = 400 psia (T_{sat} = 179.86°F)			
Sat.	0.23001	110.13	118.64	0.21757	0.14279	112.61	120.54	0.21517	0.09643	113.36	120.50	0.21164
140	0.24541	113.86	122.94	0.22483								
160	0.26412	118.67	128.44	0.23386	0.14656	113.82	121.96	0.21747				
180	0.28115	123.36	133.77	0.24231	0.16355	119.53	128.61	0.22803	0.09658	113.42	120.56	0.21174
200	0.29704	128.01	139.00	0.25037	0.17776	124.79	134.66	0.23734	0.11440	120.53	128.99	0.22473
220	0.31212	132.65	144.20	0.25813	0.19044	129.86	140.43	0.24596	0.12746	126.45	135.88	0.23502
240	0.32658	137.31	149.39	0.26566	0.20211	134.83	146.05	0.25412	0.13853	131.96	142.21	0.24420
260	0.34054	141.99	154.60	0.27300	0.21306	139.77	151.60	0.26193	0.14844	137.27	148.26	0.25272
280	0.35410	146.73	159.83	0.28017	0.22347	144.71	157.11	0.26949	0.15756	142.48	154.15	0.26079
300	0.36733	151.50	165.10	0.28720	0.23346	149.66	162.62	0.27683	0.16611	147.65	159.95	0.26853
320	0.38029	156.34	170.41	0.29410	0.24310	154.63	168.13	0.28399	0.17423	152.81	165.71	0.27601
340	0.39300	161.23	175.77	0.30089	0.25246	159.65	173.66	0.29100	0.18201	157.97	171.45	0.28328
360	0.40552	166.18	181.19	0.30758	0.26159	164.71	179.23	0.29788	0.18951	163.16	177.19	0.29037

Summary

- **Conservation of mass**
  - Mass and volume flow rates
  - Mass balance for a steady-flow process
  - Mass balance for incompressible flow
- **Flow work and the energy of a flowing fluid**
  - Energy transport by mass
- **Energy analysis of steady-flow systems**
- **Some steady-flow engineering devices**
  - Nozzles and Diffusers
  - Turbines and Compressors
  - Throttling valves
  - Mixing chambers and Heat exchangers
  - Pipe and Duct flow
- **Energy analysis of unsteady-flow processes**